

Lembrechts, Jonas, Aalto, Juha, Bailey,
Joseph ORCID: <https://orcid.org/0000-0002-9526-7095>, Ashcroft,
Michael and et al., (2020) SoilTemp: call for data for a global
database of near-surface temperature. Global Change Biology.

Downloaded from: <http://ray.yorks.ac.uk/id/eprint/4534/>

The version presented here may differ from the published version or version of record. If
you intend to cite from the work you are advised to consult the publisher's version:
<https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.15123>

Research at York St John (RaY) is an institutional repository. It supports the principles of
open access by making the research outputs of the University available in digital form.
Copyright of the items stored in RaY reside with the authors and/or other copyright
owners. Users may access full text items free of charge, and may download a copy for
private study or non-commercial research. For further reuse terms, see licence terms
governing individual outputs. [Institutional Repository Policy Statement](#)

RaY

Research at the University of York St John

For more information please contact RaY at ray@yorks.ac.uk

MR. JONAS J. LEMBRECHTS (Orcid ID : 0000-0002-1933-0750)

MR. JUHA AALTO (Orcid ID : 0000-0001-6819-4911)

DR. MICHAEL B ASHCROFT (Orcid ID : 0000-0003-2157-5965)

DR. PIETER DE FRENNE (Orcid ID : 0000-0002-8613-0943)

MR. MARTIN KOPECKÝ (Orcid ID : 0000-0002-1018-9316)

DR. ILYA M D MACLEAN (Orcid ID : 0000-0001-8030-9136)

DR. JUHA ALATALO (Orcid ID : 0000-0001-5084-850X)

DR. ROBERT G. BJÖRK (Orcid ID : 0000-0001-7346-666X)

DR. MARTIN SVATEK (Orcid ID : 0000-0003-2328-4627)

PROF. ALISTAIR JUMP (Orcid ID : 0000-0002-2167-6451)

DR. ELLEN DORREPAAL (Orcid ID : 0000-0002-0523-2471)

DR. MICHELE CARBOGNANI (Orcid ID : 0000-0001-7701-9859)

DR. KOENRAAD VAN MEERBEEK (Orcid ID : 0000-0002-9260-3815)

DR. JIRI DOLEZAL (Orcid ID : 0000-0002-5829-4051)

MS. JULIA KEMPPINEN (Orcid ID : 0000-0001-7521-7229)

MR. PEKKA NIITYNEN (Orcid ID : 0000-0002-7290-029X)

PROF. JUERGEN KREYLING (Orcid ID : 0000-0001-8489-7289)

MS. SANNE GOVAERT (Orcid ID : 0000-0002-8939-1305)

MS. ANDREA LAMPRECHT (Orcid ID : 0000-0002-8719-026X)

DR. SYLVIA HAIDER (Orcid ID : 0000-0002-2966-0534)

PROF. MARTIN WILMKING (Orcid ID : 0000-0003-4964-2402)

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the [Version of Record](#). Please cite this article as [doi: 10.1111/GCB.15123](https://doi.org/10.1111/GCB.15123)

This article is protected by copyright. All rights reserved

DR. JAN ALTMAN (Orcid ID : 0000-0003-4879-5773)

MR. MARTIN MACEK (Orcid ID : 0000-0002-5609-5921)

DR. MARIJN BAUTERS (Orcid ID : 0000-0003-0978-6639)

DR. MIGUEL PORTILLO-ESTRADA (Orcid ID : 0000-0002-0348-7446)

DR. ISLA H MYERS-SMITH (Orcid ID : 0000-0002-8417-6112)

DR. JÖRG G. STEPHAN (Orcid ID : 0000-0001-6195-7867)

MR. PATRICE DESCOMBES (Orcid ID : 0000-0002-3760-9907)

MR. CHRISTOPHER ANDREWS (Orcid ID : 0000-0003-2428-272X)

DR. REBECCA ANNE SENIOR (Orcid ID : 0000-0002-8208-736X)

DR. FATIH FAZLIOGLU (Orcid ID : 0000-0002-4723-3640)

DR. FERNANDO MOYANO (Orcid ID : 0000-0002-4090-5838)

Article type : Report

SoilTemp: a global database of near-surface temperature

Running title – SoilTemp: call for data

Jonas J. Lembrechts¹, Juha Aalto^{2,3}, Michael B. Ashcroft^{4,5}, Pieter De Frenne⁶, Martin Kopecký^{7,8}, Jonathan Lenoir⁹, Miska Luoto³, Ilya M. D. Maclean¹⁰, Olivier Roupsard^{11,12}, Eduardo Fuentes-Lillo^{13,14,15,1}, Rafael A. García^{13,14}, Loïc Pellissier^{16,17}, Camille Pitteloud^{16,17}, Juha M. Alatalo^{18,19}, Stuart W. Smith^{20,21}, Robert G. Björk^{22,23}, Lena Muffler^{24,25}, Simone Cesarz^{26,27}, Felix Gottschall^{26,27}, Amanda Ratier Backes^{28,26}, Joseph Okello^{29,30}, Josef Urban^{31,32}, Roman Plichta³¹, Martin Svátek³¹, Shyam S. Phartyal^{33,34}, Sonja

Wipf^{35,36}, Nico Eisenhauer^{26,27}, Mihai Pușcaș³⁷, Pavel Dan Turtureanu³⁸, Andrej Varlagin³⁹, Romina D. Dimarco⁴⁰, Alistair S. Jump⁴¹, Krystal Randall⁴², Ellen Dorrepaal⁴³, Keith Larson⁴³, Josefine Walz⁴³, Luca Vitale⁴⁴, Miroslav Svoboda⁸, Rebecca Finger Higgins⁴⁵, Aud H. Halbritter⁴⁶, Salvatore R. Curasi⁴⁷, Ian Klupar⁴⁷, Austin Koontz⁴⁸, William D. Pearse^{48,49}, Elizabeth Simpson⁴⁸, Michael Stemkovski⁴⁸, Bente Jessen Graae²⁰, Mia Vedel Sørensen²⁰, Toke T. Høye⁵⁰, M. Rosa Fernández Calzado⁵¹, Juan Lorite⁵¹, Michele Carbognani⁵², Marcello Tomaselli⁵², T'ai G. W. Forte⁵², Alessandro Petraglia⁵², Stef Haesen⁵³, Ben Somers⁵³, Koenraad Van Meerbeek⁵³, Mats P. Björkman^{22,23}, Kristoffer Hylander⁵⁴, Sonia Merinero⁵⁵, Mana Gharun⁵⁶, Nina Buchmann⁵⁶, Jiri Dolezal^{7,57}, Radim Matula⁸, Andrew D. Thomas⁵⁸, Joseph J. Bailey⁵⁹, Dany Ghosn⁶⁰, George Kazakis⁶⁰, Miguel Angel de Pablo⁶¹, Julia Kemppinen³, Pekka Niittynen³, Lisa Rew⁶², Tim Seipel⁶², Christian Larson⁶², James D. M. Speed⁶³, Jonas Ardö⁶⁴, Nicoletta Cannone⁶⁵, Mauro Guglielmin⁶⁶, Francesco Malfasi⁶⁶, Maaike Y. Bader⁶⁷, Rafaella Canessa⁶⁷, Angela Stanisci⁶⁸, Juergen Kreyling²⁴, Jonas Schmeddes²⁴, Laurenz Teuber²⁴, Valeria Aschero^{69,70}, Marek Čiliak⁷¹, František Máliš⁷², Pallieter De Smedt⁶, Sanne Govaert⁶, Camille Meeussen⁶, Pieter Vangansbeke⁶, Khatuna Gigauri⁷³, Andrea Lamprecht⁷⁴, Harald Pauli⁷⁴, Klaus Steinbauer⁷⁴, Manuela Winkler⁷⁴, Masahito Ueyama⁷⁵, Martin A. Nuñez⁷⁶, Tudor-Mihai Ursu⁷⁷, Sylvia Haider^{28,26}, Ronja E. M. Wedegärtner²⁰, Marko Smiljanic⁷⁸, Mario Trouillier⁷⁸, Martin Wilmking⁷⁸, Jan Altman⁷, Josef Brůna⁷, Lucia Hederová⁷, Martin Macek⁷, Matěj Man⁷, Jan Wild⁷, Pascal Vittoz⁷⁹, Meelis Pärtel⁸⁰, Peter Barančok⁸¹, Róbert Kanka⁸¹, Jozef Kollár⁸¹, Andrej Palaj⁸¹, Agustina Barros⁷⁰, Ana Clara Mazzolari⁷⁰, Marijn Bauters²⁹, Pascal Boeckx²⁹, José Luis Benito Alonso⁸², Shengwei Zong⁸³, Valter Di Cecco⁸⁴, Zuzana Sitková⁸⁵, Katja Tielbörger⁸⁶, Liesbeth van den Brink⁸⁶, Robert Weigel²⁵, Jürgen Homeier²⁵, C. Johan Dahlberg^{54,87}, Sergiy Medinets⁸⁸, Volodymyr Medinets⁸⁸, Hans J. De Boeck¹, Miguel Portillo-Estrada¹, Lore T. Verryckt¹, Ann Milbau⁸⁹, Gergana N. Daskalova⁹⁰, Haydn J. D. Thomas⁹⁰, Isla H. Myers-Smith⁹⁰, Benjamin Blonder^{91,92}, Jörg G. Stephan⁹³, Patrice Descombes^{16,17,94}, Florian Zellweger⁹⁴, Esther R. Frei^{35,94}, Bernard Heinesch⁹⁵, Christopher Andrews⁹⁶, Jan Dick⁹⁶, Lukas Siebicke⁹⁷, Adrian Rocha⁹⁸, Rebecca A. Senior⁹⁹, Christian Rixen³⁵, Juan J. Jimenez¹⁰⁰, Julia Boike^{101,102}, Aníbal Pauchard^{13,14}, Thomas Scholten¹⁰³, Brett Scheffers¹⁰⁴, David Klinges¹⁰⁵, Edmund W. Basham¹⁰⁵, Jian Zhang¹⁰⁶, Zhaochen Zhang¹⁰⁶, Charly Géron¹⁰⁷, Fatih Fazlioglu¹⁰⁸, Onur Candan¹⁰⁸, Jhonatan Sallo Bravo¹⁰⁹, Filip Hrbacek¹¹⁰, Kamil Laska¹¹⁰, Edoardo Cremonese¹¹¹, Peter Haase^{112,113}, Fernando E. Moyano⁹⁷, Christian Rossi^{114,115,36}, Ivan Nijs¹

Author contributions: JLL performed the analyses and wrote the manuscript , JLL, JA, MBA, PDF, MK, JL, ML, IMDM and IN lead the consortium and contributed to the writing; all authors contribute to the consortium and provided editorial advice.

*Corresponding author, OrcID = <https://orcid.org/0000-0002-1933-0750>,
Jonas.lembrechts@uantwerpen.be, +3232651727

OrcIDs (alphabetically ordered)

Juha Aalto <https://orcid.org/0000-0001-6819-4911>
Juha M. Alatalo <https://orcid.org/0000-0001-5084-850X>
Jan Altman <https://orcid.org/0000-0003-4879-5773>
Jonas Ardö <https://orcid.org/0000-0002-9318-0973>
Valeria Aschero <https://orcid.org/0000-0003-3865-4133>
Maaike Y Bader <http://orcid.org/0000-0003-4300-7598>
Peter Barančok <https://orcid.org/0000-0003-1171-2524>
Edmund Basham <https://orcid.org/0000-0002-0167-7908>
José-Luis Benito-Alonso <https://orcid.org/0000-0003-1086-8834>
Robert G. Björk <https://orcid.org/0000-0001-7346-666X>
Mats P. Björkman <https://orcid.org/0000-0001-5768-1976>
Julia Boike <https://orcid.org/0000-0002-5875-2112>
Josef Brůna <https://orcid.org/0000-0002-4839-4593>
Nina Buchmann <https://orcid.org/0000-0003-0826-2980>
Onur Candan <https://orcid.org/0000-0002-9254-4122>
Rafaella Canessa <https://orcid.org/0000-0002-6979-9880>
Michele Carbognani <https://orcid.org/0000-0001-7701-9859>
Marek Čiliak <https://orcid.org/0000-0002-6720-9365>
Edoardo Cremonese <https://orcid.org/0000-0002-6708-8532>
Salvatore R. Curasi: <https://orcid.org/0000-0002-4534-3344>
C. Johan Dahlberg <https://orcid.org/0000-0003-0271-3306>
Gergana Daskalova <https://orcid.org/0000-0002-5674-5322>
Miguel Ángel de Pablo Hernández <https://orcid.org/0000-0002-4496-2741>
Pallietier De Smedt <https://orcid.org/0000-0002-3073-6751>
Jiri Dolezal <https://orcid.org/0000-0002-5829-4051>
Nico Eisenhower <https://orcid.org/0000-0002-0371-6720>
Fatih Fazlioglu <https://orcid.org/0000-0002-4723-3640>
T'ai G. W. Forte <https://orcid.org/0000-0002-8685-5872>
Esther R. Frei <https://orcid.org/0000-0003-1910-7900>
Charly Geron: <https://orcid.org/0000-0001-7912-4708>
Mana Gharun <https://orcid.org/0000-0003-0337-7367>
Dany Ghosn <https://orcid.org/0000-0003-1898-9681>
Felix Gottschall <https://orcid.org/0000-0002-1247-8728>
Sanne Govaert <https://orcid.org/0000-0002-8939-1305>
Peter Haase <https://orcid.org/0000-0002-9340-0438>

Stef Haesen <https://orcid.org/0000-0002-4491-4213>
Sylvia Haider <https://orcid.org/0000-0002-2966-0534>
Bernard Heinesch <https://orcid.org/0000-0001-7594-6341>
Toke T. Høye <https://orcid.org/0000-0001-5387-3284>
Filip Hrbacek <https://orcid.org/0000-0001-5032-9216>
Juan J. Jiménez <https://orcid.org/0000-0003-2398-0796>
Alistair S. Jump <https://orcid.org/0000-0002-2167-6451>
Róbert Kanka <https://orcid.org/0000-0002-7071-7280>
Julia Kempainen <https://orcid.org/0000-0001-7521-7229>
Austin Koontz <https://orcid.org/0000-0002-6103-5894>
Andrea Lamprecht <https://orcid.org/0000-0002-8719-026X>
Christian Larson <https://orcid.org/0000-0002-7567-4953>
Kamil Laska <https://orcid.org/0000-0002-5199-9737>
Jonathan Lenoir <http://orcid.org/0000-0003-0638-9582>
Juan Lorite <https://orcid.org/0000-0003-4617-8069>
František Máliš <https://orcid.org/0000-0003-2760-6988>
Matěj Man <https://orcid.org/0000-0002-4557-8768>
Sergiy Medinets <http://orcid.org/0000-0001-5980-1054>
Volodymyr Medinets <https://orcid.org/0000-0001-7543-7504>
Camille Meeussen <https://orcid.org/0000-0002-5869-4936>
Ann Milbau <https://orcid.org/0000-0003-3555-8883>
Fernando E. Moyano <https://orcid.org/0000-0002-4090-5838>
Lena Muffler <https://orcid.org/0000-0001-8227-7297>
Isla Myers-Smith <https://orcid.org/0000-0002-8417-6112>
Pekka Niittynen <https://orcid.org/0000-0002-7290-029X>
Ivan Nijs <https://orcid.org/0000-0003-3111-680X>
Andrej Palaj <https://orcid.org/0000-0001-7054-4183>
Harald Pauli <https://orcid.org/0000-0002-9842-9934>
William D. Pearse <https://orcid.org/0000-0002-6241-3164>
Shyam S. Phartyal <https://orcid.org/0000-0003-3266-6619>
Mihai Puşcaş <https://orcid.org/0000-0002-2632-640X>
Krystal Randall <https://orcid.org/0000-0003-2507-1000>
Lisa Rew <https://orcid.org/0000-0002-2818-3991>
Christian Rossi <https://orcid.org/0000-0001-9983-8898>
Olivier Rounsard <http://orcid.org/0000-0002-1319-142X>
Jhonatan Sallo-Bravo <https://orcid.org/0000-0001-9007-4959>
Brett Scheffers <https://orcid.org/0000-0003-2423-3821>
Thomas Scholten <https://orcid.org/0000-0002-4875-2602>
Rebecca A. Senior <https://orcid.org/0000-0002-8208-736X>
Zuzana Sitková <https://orcid.org/0000-0001-6354-6105>
Stuart W. Smith <https://orcid.org/0000-0001-9396-6610>
Ben Somers <https://orcid.org/0000-0002-7875-107X>
James D. M. Speed <http://orcid.org/0000-0002-0633-5595>
Klaus Steinbauer <https://orcid.org/0000-0002-3730-9920>
Jörg G. Stephan <http://orcid.org/0000-0001-6195-7867>

Martin Svátek <https://orcid.org/0000-0003-2328-4627>
Miroslav Svoboda <https://orcid.org/0000-0003-4050-3422>
Andrew Thomas <https://orcid.org/0000-0002-1360-1687>
Haydn Thomas <https://orcid.org/0000-0001-9099-6304>
Marcello Tomaselli <https://orcid.org/0000-0003-4208-3433>
Pavel Dan Turtureanu <https://orcid.org/0000-0002-7422-3106>
Masahito Ueyama <https://orcid.org/0000-0002-4000-4888>
Josef Urban <https://orcid.org/0000-0003-1730-947X>
Tudor-Mihai Ursu <https://orcid.org/0000-0002-4898-6345>
Liesbeth van den Brink <https://orcid.org/0000-0003-0313-8147>
Pieter Vangansbeke <https://orcid.org/0000-0002-6356-2858>
Andrej Varlagin <https://orcid.org/0000-0002-2549-5236>
Koenraad Van Meerbeek <https://orcid.org/0000-0002-9260-3815>
Lore T. Verryckt <https://orcid.org/0000-0002-9452-5216>
Pascal Vittoz <https://orcid.org/0000-0003-4218-4517>
Josefine Walz <https://orcid.org/0000-0002-0715-8738>
Ronja E. M. Wedegärtner <https://orcid.org/0000-0003-4633-755X>
Robert Weigel <https://orcid.org/0000-0001-9685-6783>
Jan Wild <https://orcid.org/0000-0003-3007-4070>
Martin Wilmking <https://orcid.org/0000-0003-4964-2402>
Manuela Winkler <http://orcid.org/0000-0002-8655-9555>
Sonja Wipf <http://orcid.org/0000-0002-3492-1399>
Florian Zellweger <https://orcid.org/0000-0003-1265-9147>
Jian Zhang <https://orcid.org/0000-0003-0589-6267>

¹ Research Group PLECO (Plants and Ecosystems), University of Antwerp, 2610 Wilrijk, Belgium, ² Finnish Meteorological Inst., P.O. Box 503, FI-00101 Helsinki, Finland, ³ Dept of Geosciences and Geography, Gustaf Hållströmin katu 2a, FIN-00014 Univ. of Helsinki, Finland, ⁴ Centre for Sustainable Ecosystem Solutions, School of Biological Sciences, University of Wollongong, Wollongong, Australia, ⁵ Australian Museum, Sydney, Australia, ⁶ Forest & Nature Lab, Department of Environment, Ghent University, Geraardsbergsesteenweg 267, 9090 Melle-Gontrode, Belgium, ⁷ Institute of Botany of the Czech Academy of Sciences, Zámek 1, CZ-25243, Průhonice, Czech Republic, ⁸ Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, CZ-165 21, Prague 6 - Suchbát, Czech Republic, ⁹ UR 'Ecologie et Dynamique des Systèmes Anthropisés' (EDYSAN, UMR 7058 CNRS-UPJV), Univ. de Picardie Jules Verne, Amiens, France, ¹⁰ Environment and Sustainability Institute, University of Exeter, Penryn Campus, Penryn, UK, TR10 9FE, ¹¹ CIRAD, UMR Eco&Sols, B.P. 1386, CP 18524, Dakar, Senegal, ¹² Eco&Sols, Univ Montpellier, CIRAD, INRAE, IRD, Institut Agro, Montpellier, France, ¹³ Laboratorio de Invasiones Biológicas (LIB), Facultad de Ciencias Forestales, Universidad de Concepción, Concepción, Chile, ¹⁴ Instituto de Ecología y Biodiversidad (IEB), Santiago, Chile, ¹⁵ School of Education and Social Sciences, Adventist University of Chile, Chile, ¹⁶ Landscape Ecology, Institute of Terrestrial Ecosystems, Department of Environmental Systems Science, ETH Zürich, 8092 Zürich, Switzerland, ¹⁷ Unit of Land Change Science, Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland, ¹⁸ Department of Biological and Environmental Sciences, Qatar University, Doha, Qatar, ¹⁹ Environmental Science Center, Qatar University, Doha, Qatar, ²⁰ Department of Biology, Norwegian University of Science and Technology, 7491 Trondheim, Norway, ²¹ Asian School of Environment, Nanyang Technological University, 42 Nanyang Ave, Singapore 639815, Singapore, ²² Department of Earth Sciences, University of Gothenburg, P.O. Box 460, SE-40530 Gothenburg, Sweden, ²³ Gothenburg Global Biodiversity Centre, P.O. Box 461, SE-405 30 Gothenburg, Sweden, ²⁴ Experimental Plant Ecology, Institute of Botany and Landscape Ecology, University of Greifswald, D-17487 Greifswald, Germany, ²⁵ Plant Ecology, Albrecht-von-Haller-Institute for Plant Sciences, University of Göttingen, 37073 Göttingen, Germany, ²⁶ German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany, ²⁷ Institute of Biology, Leipzig University, Leipzig, Germany, ²⁸ Institute of Biology / Geobotany and Botanical Garden, Martin Luther University Halle-Wittenberg, Halle (Saale), Germany, ²⁹ Isotope Bioscience Laboratory - ISOFYS, Ghent University, Coupure Links 653, 9000 Gent, Belgium, ³⁰ Mountains of the Moon University, P.O Box 837, Fort Portal, Uganda, ³¹ Department of Forest Botany, Dendrology and Geobiocoenology, Mendel University in Brno, Czech Republic, ³² Siberian Federal University, Krasnoyarsk, Russia, ³³ School of Ecology and Environment Studies, Nalanda University, Rajgir, India, ³⁴ Department of Forestry and NR, H.N.B. Garhwal University, Srinagar-Garhwal, India, ³⁵ WSL Institute for Snow and Avalanche Research SLF, 7260 Davos, Switzerland, ³⁶ Swiss National Park, Chastè Planta-Wildenberg, 7530 Zermatt, Switzerland, ³⁷ A. Borza Botanical Garden and Department of Taxonomy and Ecology, Faculty of Biology and Geology, Babeş-Bolyai University, Cluj-Napoca, Romania, ³⁸ A. Borza Botanical Garden, Babeş-Bolyai University, Cluj-Napoca, Romania, ³⁹ A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, 119071, Leninsky pr.33, Moscow, Russia, ⁴⁰ Grupo de Ecología de Poblaciones de Insectos, IFAB (INTA - CONICET), Isla Victoria 4450, Bariloche, Argentina, ⁴¹ Biological and Environmental Sciences, Faculty of Natural Sciences, University of Stirling, Scotland, FK9 4LA, ⁴² Centre for Sustainable Ecosystem Solutions, School of Earth, Atmospheric and Life Sciences, University of Wollongong, Wollongong, New South Wales, 2522, Australia, ⁴³ Climate Impacts Research Centre, Department of Ecology and Environmental Sciences, Umeå University, Abisko, Sweden, ⁴⁴ CNR - Institute for mediterranean Agricultural and Forest Systems, Via Patacca 85, ercolano (napoli), Italy, ⁴⁵ Dartmouth College, Hanover, NH, USA, ⁴⁶ Department of Biological Sciences and Bjerknes Centre for Climate Research, University of Bergen, N-5020 Bergen, Norway, ⁴⁷ Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA, ⁴⁸ Department of Biology and Ecology Center, Utah State University, 5305 Old Main Hill, Logan, UT 84322, USA, ⁴⁹ Department of Life Sciences, Imperial College, Silwood Park Campus, Ascot, Berkshire SL5 7PY, UK, ⁵⁰ Department of Bioscience and Arctic Research Centre, Grenåvej 14, 8410 Rønne, Denmark, ⁵¹ Department of Botany, University of Granada,

18071, Granada, Spain, ⁵² Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parco Area delle Scienze 11/A, 43124 Parma, Italy, ⁵³ Department of Earth and Environmental Sciences, Celestijnenlaan 200E, 3001 Leuven, Belgium, ⁵⁴ Department of Ecology, Environment and Plant Sciences and Bolin Centre for Climate Research, Stockholm University, 106 91 Stockholm, Sweden, ⁵⁵ Department of Ecology, Environment and Plant Sciences, Stockholm University, SE-106 91 Stockholm, Sweden, ⁵⁶ Department of Environmental Systems Science, ETH Zurich, Universitaetstrasse 2, 8092 Zurich, Switzerland, ⁵⁷ Faculty of Science, Department of Botany, University of South Bohemia, Na Zlaté Stoce 1, 37005 České Budějovice, Czech Republic, ⁵⁸ Department of Geography and Earth Sciences, Aberystwyth University, Wales, UK, ⁵⁹ Department of Geography, York St John University, Lord Mayor's Walk, York, YO31 7EX, United Kingdom, ⁶⁰ Department of Geo-information in Environmental Management, Mediterranean Agronomic Institute of Chania, PO Box 85, 73100 Chania, Greece, ⁶¹ Department of Geology, Geography and Environment. University of Alcalá. 28805 Alcalá de Henares, Madrid, Spain., ⁶² Department of Land Resources and Environmental Sciences, Montana State University, Bozeman MT, USA, 59717, ⁶³ Department of Natural History, NTNU University Museum, Norwegian University of Science and Technology, NO-7491 Trondheim Norway, ⁶⁴ Department of Physical Geography and Ecosystem Science, Lund University, Sölvegatan 12 223 62 Lund Sweden, ⁶⁵ Department of Science and High Technology, Insubria University, Via Valleggio 11, 22100 Como, Italy, ⁶⁶ Department of Theoretical and Applied Sciences, Insubria University, Via Dunant 3, 21100 Varese, Italy, ⁶⁷ Ecological Plant Geography, Faculty of Geography, University of Marburg, Deutschhausstr. 10, 35032, Marburg, Germany, ⁶⁸ EnvixLab, Dipartimento di Bioscienze e Territorio, Università degli Studi del Molise, Via Duca degli Abruzzi s.n.c., 86039 Termoli, Italy, ⁶⁹ Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Cuyo, ⁷⁰ Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), CONICET, CCT-Mendoza, ⁷¹ Faculty of Ecology and Environmental Sciences, Technical University in Zvolen, T.G.Masaryka 24, 960 01 Zvolen, Slovakia, ⁷² Faculty of Forestry, Technical University in Zvolen, T.G.Masaryka 24, 960 01 Zvolen, Slovakia, ⁷³ Georgian Institute of Public Affairs, Tbilisi, Georgia, ⁷⁴ GLORIA Coordination, Institute for Interdisciplinary Mountain Research, Austrian Academy of Sciences (ÖAW) & Department of Integrative Biology and Biodiversity Research, University of Natural Resources and Life Sciences Vienna (BOKU), Silbergasse 30/3, 1190 Vienna, Austria, ⁷⁵ Graduate School of Life and Environmental Sciences, Osaka Prefecture University, 599-8531, Japan, ⁷⁶ Grupo de Ecología de Invasiones, INIBIOMA, CONICET/ Universidad Nacional del Comahue, Av. de los Pioneros 2350, Bariloche 8400, Argentina, ⁷⁷ Institute of Biological Research Cluj-Napoca, National Institute of Research and Development for Biological Sciences, Bucharest, Romania, ⁷⁸ Institute of Botany and Landscape Ecology, University Greifswald, D-17487 Greifswald, Germany, ⁷⁹ Institute of Earth Surface Dynamics, Faculty of Geosciences and Environment, University of Lausanne, Géopolis, 1015 Lausanne, Switzerland, ⁸⁰ Institute of Ecology and Earth Sciences, University of Tartu, Lai 40, Tartu 51005, Estonia, ⁸¹ Institute of Landscape Ecology Slovak Academy of Sciences, Štefánikova 3, 81499 Bratislava, Slovakia, ⁸² Jolube Consultor Botánico. C/Mariano R de Ledesma, 4. E-22700 Jaca, Huesca, SPAIN, ⁸³ Key Laboratory of Geographical Processes and Ecological Security in Changbai Mountains, Ministry of Education, School of Geographical Sciences, Northeast Normal University, Changchun 130024, China, ⁸⁴ Majella Seed Bank, Majella National Park, Colle Madonna, 66010 Lama dei Peligni, Italy, ⁸⁵ National Forest Centre, Forest Research Institute Zvolen, T. G. Masaryka 22, 96001 Zvolen, Slovakia, ⁸⁶ Plant Ecology Group, Department of Evolution and Ecology, University of Tübingen, Tübingen, Germany, ⁸⁷ the County Administrative Board of Västra Götaland, SE-403 40 Gothenburg, Sweden, ⁸⁸ Regional Centre for Integrated Environmental Monitoring, Odesa National I.I. Mechnikov University, 7 Mayakovskogo lane, 65082 Odesa, Ukraine, ⁸⁹ Research Institute for Nature and Forest (INBO), Havenlaan 88, bus 73, 1000 Brussel, Belgium, ⁹⁰ School of GeoSciences, University of Edinburgh, King's Buildings, Edinburgh, EH9 3FF, United Kingdom, ⁹¹ School of Life Sciences, Arizona State University, Tempe, AZ, USA, ⁹² Department of Environmental Science, Policy, and Management, University of California, Berkeley, CA 94720 USA, ⁹³ Swedish University of Agricultural Sciences, Swedish Species Information Centre, Almas allé 8 E, 75651 Uppsala, Sweden, ⁹⁴ Swiss Federal Research Institute WSL, 8903 Birmensdorf,

Switzerland, ⁹⁵ TERRA Teaching and Research Center, Faculty of Gembloux Agro-Bio Tech, University of Liege, Passage des déportés, 2, 5030 Gembloux, Belgium, ⁹⁶ UK Centre for Ecology & Hydrology, Bush Estate, Penicuik, Midlothian, EH26 0QB, United Kingdom, ⁹⁷ University of Goettingen, Bioclimatology, Büsgenweg 2, 37077 Göttingen, Germany., ⁹⁸ University of Notre Dame, Department of Biological Sciences and the Environmental Change Initiative, ⁹⁹ Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ 08540, USA, ¹⁰⁰ ARAID Research and Development, Zaragoza, Spain, ¹⁰¹ Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Telegrafenberg A45, 14473 Potsdam, Germany, ¹⁰² Geography Department, Humboldt-Universität zu Berlin, Germany, ¹⁰³ Chair of Soil Science and Geomorphology, Department of Geosciences, University of Tuebingen, 72070 Tuebingen, Germany, ¹⁰⁴ Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL 32611, USA, ¹⁰⁵ School of Natural Resources and Environment, University of Florida, Gainesville, FL 32611, USA, ¹⁰⁶ Zhejiang Tiantong Forest Ecosystem National Observation and Research Station, School of Ecological and Environmental Sciences, East China Normal University, Shanghai 200241, China, ¹⁰⁷ Biodiversity and Landscape, TERRA research centre, Gembloux Agro-Bio Tech, University of Liège, Gembloux, 5032, Belgium ; Research Group PLECO (Plants and Ecosystems), University of Antwerp, 2610 Wilrijk, Belgium, ¹⁰⁸ Faculty of Arts and Sciences, Department of Molecular Biology and Genetics, Ordu University, 52200, Ordu, Turkey, ¹⁰⁹ Universidad Nacional de San Antonio Abad del Cusco, Cusco, Peru, ¹¹⁰ Department of Geography, Masaryk University, Brno, Czech Republic, ¹¹¹ Climate Change Unit, Environmental Protection Agency of Aosta Valley, Sain Christophe, Aosta, Italy, ¹¹² Senckenberg Research Institute and Natural History Museum Frankfurt, 63571 Gelnhausen, Germany, ¹¹³ Faculty of Biology, University of Duisburg-Essen, 45141 Essen, Germany, ¹¹⁴ Remote Sensing Laboratories, Dept. of Geography, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland, ¹¹⁵ Research Unit Community Ecology, Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland

1 Abstract

2 Current analyses and predictions of spatially-explicit patterns and processes in ecology most often rely on
3 climate data interpolated from standardized weather stations. This interpolated climate data represents
4 long-term average thermal conditions at coarse spatial resolutions only. Hence, many climate-forcing
5 factors that operate at fine spatiotemporal resolutions are overlooked. This is particularly important in
6 relation to effects of observation height (e.g. vegetation, snow and soil characteristics) and in habitats
7 varying in their exposure to radiation, moisture and wind (e.g. topography, radiative forcing, or cold-air
8 pooling). Since organisms living close to the ground relate more strongly to these microclimatic conditions
9 than to free-air temperatures, microclimatic ground and near-surface data are needed to provide realistic
10 forecasts of the fate of such organisms under anthropogenic climate change, as well as of the functioning
11 of the ecosystems they live in.

12 To fill this critical gap, we highlight a call for temperature time series submissions to SoilTemp, a
13 geospatial database initiative compiling soil and near-surface temperature data from all over the world.
14 Currently this database contains time series from 7538 temperature sensors from 51 countries across all
15 key biomes. The database will pave the way towards an improved global understanding of microclimate
16 and bridge the gap between the available climate data and the climate at fine spatiotemporal resolutions
17 relevant to most organisms and ecosystem processes.

18 **Keywords:** microclimate, soil climate, climate change, topoclimate, database, temperature, species
19 distributions, ecosystem processes

20 **Introduction**

21 Current ecological research increasingly deals with large-scale patterns and processes, with global
22 databases of species distributions and traits becoming increasingly available (Bruehlheide *et al.*, 2018,
23 Kissling *et al.*, 2018, Kattge *et al.*, 2019). Analyses of these patterns and processes – and their predictions
24 under anthropogenic climate change – often rely on global climatic grids at coarse spatial resolutions
25 interpolated from standardized weather stations that represent long-term average atmospheric
26 conditions (Lembrechts *et al.*, 2018). Moreover, sensors in these weather stations are shielded from direct
27 solar radiation and located at ~2 meters above a frequently mown lawn (free-air temperature or
28 'macroclimate', Jarraud, 2008). These climatic grids thus ignore many climate-forcing processes that
29 operate near the ground surface, at fine spatiotemporal resolutions, and in environments that vary in
30 their exposure to winds, radiation and moisture ('microclimate', Daly, 2006, Bramer *et al.*, 2018, Körner &
31 Hiltbrunner, 2018). Importantly, while these microclimatic processes often operate at fine spatiotemporal
32 resolutions, they can affect ecological relations both at the local and the global scale (De Frenne *et al.*,
33 2013, Ashcroft *et al.*, 2014, Lembrechts *et al.*, 2019). For example, they can potentially protect ground-
34 dwelling biota against long-term climate variability, providing microrefugia for these species to survive in
35 locations deemed unsuitable in models using climate data at coarse spatial resolutions, or buffer
36 organisms against short-term extreme events (De Frenne *et al.*, 2013, Lenoir *et al.*, 2017, Bramer *et al.*,
37 2018, Suggitt *et al.*, 2018). Microclimates can however also expose organisms to more extreme
38 temperatures, in which case distribution models that ignore such microclimates may erroneously predict
39 species survival instead of extinction (Pincebourde & Casas, 2019). In order to provide realistic forecasts
40 of species distributions and performance, as well as of the functioning of the ecosystems they operate in,
41 climate data that incorporates microclimatic processes, ideally measured *in-situ*, are thus urgently needed
42 (Körner & Hiltbrunner, 2018).

43 **Horizontal and vertical features driving microclimate**

44 The offset between micro- and macroclimate is particularly pronounced around the soil surface, as
45 temperatures measured at 2 m above the ground can differ substantially from those at ground level, or in
46 the layers just above and below it (Geiger, 1950, Lembrechts *et al.*, 2019). This offset can result from both
47 'horizontal' and 'vertical' features (Fig. 1), and can exceed several degrees centigrade in annual averages.
48 For example, Kearney (2019) modelled coarse-scale soil temperatures at various depths considering the
49 vertical features affecting the radiation balance. These vertical features include the effects of vegetation
50 characteristics (e.g. structure and cover), snow cover and soil characteristics (e.g. moisture content,

geological types, texture and bulk density) (Li, 1926, Zhang *et al.*, 2008, Lembrechts *et al.*, 2019). The result of these vertical features is not only an instantaneous temperature offset between air and soil temperatures, but also a buffering effect, i.e. the temporal variability in temperature changes is lower in the soil than in the air (Geiger, 1950, Ashcroft & Gollan, 2013). Horizontal processes on the other hand relate more to the spatial resolution of the climatic data. They can be broken up into those that require only fine-resolution environmental information for specific sites (e.g. effects of slope and aspect on radiation balances; Bennie *et al.*, 2008), and those where temperatures are also affected by neighboring locations (e.g. topographic shading, cold-air drainage and atmospheric temperature inversions, which are landscape context dependent; Whiteman, 1982, Ashcroft & Gollan, 2012).

How horizontal and vertical features interact to define differences between soil and air temperature may differ with the biome, season and day time. For example, in grasslands during summer, incoming short-wave solar radiation is usually the dominant factor determining daytime soil surface temperatures, which in turn result in higher air temperatures through convective heating (Geiger, 1950). However, during winter, horizontal processes such as cold-air drainage and coastal buffering can have larger effects, especially on overnight air temperatures, when air temperatures may be driving soil temperatures rather than vice-versa (Vitasse *et al.*, 2017). In dense forests, the situation is even more complex: upper canopies block the bulk of short wave solar radiation, such that sub-canopy temperatures are determined by convective heat transfer between the air surrounding the canopy and direct conductance through physical contact of different parts of the canopy layer, in addition to the limited radiation that does permeate the canopy (Körner & Paulsen, 2004, Lenoir *et al.*, 2017, Zellweger *et al.*, 2019). As a result, horizontal processes such as passing fronts, and winds blowing in hotter or colder air from outside the forest, will in large part define the – dampened – temperature patterns under forest canopies (Ashcroft *et al.*, 2008).

The need for microclimate data across the field of ecology

Many organisms living in the soil and close to the soil surface (e.g. soil micro-organisms like fungi, ground arthropods, herbs, mosses, tree seedlings and small vertebrates) only experience fine-scale soil and/or near-surface temperatures, and thus likely relate less strongly to free-air temperatures (Randin *et al.*, 2009, Niittynen & Luoto, 2017, Lembrechts *et al.*, 2019). This may be reflected in a species' distribution, but also their morphology, physiology and behavior (Körner & Paulsen, 2004, Kearney *et al.*, 2009, Opedal *et al.*, 2015, de Boeck *et al.*, 2016). Many species indeed survive, live and reproduce where average background climate appears unsuitable, and equally may be gone from sites within apparently suitable

82 areas where microclimatic extremes exceed their limits (Suggitt *et al.*, 2011). Without microclimate data,
83 we not only lack information on the potential thermal heterogeneity that is available for species to
84 thermoregulate in situ, but also on the true magnitude of climate change that species will be exposed to
85 (Pincebourde *et al.*, 2016, Maclean *et al.*, 2017). Accurately predicting how species' ranges will shift under
86 climate change requires a good understanding of the variety of climate niches truly available to them
87 (Maclean *et al.*, 2015, Lenoir *et al.*, 2017). The latter requires both a good understanding of what defines
88 current microclimates, as well of how climate change will interact with the drivers of microclimatic
89 conditions (Maclean, 2019). Additionally, it is the soil temperature rather than the air temperature that
90 defines many ecosystem functions in and close to the soil, like evapotranspiration, decomposition, root
91 growth, biogeochemical cycling and soil respiration (Pleim & Gilliam, 2009, Portillo-Estrada *et al.*, 2016,
92 Hursh *et al.*, 2017, Gottschall *et al.*, 2019, Medinets *et al.*, 2019). Given the repeatedly proven sensitivity
93 of many of these processes to temperatures (Rosenberg *et al.*, 1990, Coûteaux *et al.*, 1995, Schimel *et al.*,
94 1996), here again having accurate measurements will be of utmost importance. The carbon balance in
95 boreal forests, for example, is largely dependent on soil thaw and thus soil rather than air temperatures
96 (Goulden *et al.*, 1998).

97 These realizations highlight the urgency to start using soil and near-surface microclimate data when
98 modelling the ecology and biogeography of surface and soil-dwelling organisms, as well as the functioning
99 of soil ecosystems, instead of readily available coarse-scaled free-air climate data (from e.g. CHELSA
100 (Karger *et al.*, 2017), TerraClimate (Abatzoglou *et al.*, 2018) or WorldClim (Fick & Hijmans, 2017)). While a
101 suit of models now exist that produce fine-scale climate data (Bramer *et al.*, 2018, Lembrechts *et al.*,
102 2018), we do not yet fully understand whether models using data that represent average conditions over
103 large areas provide adequate “mean field approximations” of (i.e. are representative for) more complex
104 spatiotemporal effects driven by the climatic conditions that organisms experience (Bennie *et al.*, 2014).
105 To accomplish the latter, global in-situ data is needed for large-scale fine-resolution calibration and
106 validation of these models. However, while the quality and resolution of free-air temperature data and
107 models at the global scale is rapidly improving (Bramer *et al.*, 2018), soil temperature datasets used in
108 biogeography and biogeochemistry are still largely restricted to the landscape or regional scale, at best,
109 and from intensively studied regions only (Ashcroft *et al.*, 2008, Ashcroft *et al.*, 2009, Carter *et al.*, 2015,
110 Aalto *et al.*, 2018), or they are derived from models lacking fine-grained ground-truthing data (e.g.
111 Copernicus Climate Change Service (C3S), 2019). Land surface temperatures as obtained from satellite
112 data, on the other hand, are hampered by their inability to measure below the vegetation cover (Bramer
113 *et al.*, 2018).

114 In order to accurately describe and predict the (future) distribution and/or traits of surface and soil-
115 dwelling species at larger scales, we need to improve our general knowledge of the offsets and
116 spatiotemporal changes in variability between soil-level and free-air temperatures (Aalto *et al.*, 2018,
117 Lembrechts *et al.*, 2019). There is an urgent need to work towards globally available soil and near-surface
118 temperature data based on in-situ measurements and at relevant spatiotemporal resolutions (Ashcroft &
119 Gollan, 2012, Pradervand *et al.*, 2014, Slavich *et al.*, 2014, Opedal *et al.*, 2015, Meineri & Hylander, 2017).

120 ***Launch of the SoilTemp database***

121 To tackle these issues, we launch an ambitious database initiative, compiling soil and near-surface
122 temperature data from all over the world into a global geospatial database: SoilTemp. At the time of
123 writing, we brought together temperature data from 7538 sensors placed both below, at and above (up to
124 2 m) the soil surface (Fig. 2a), which is an accumulation of over 180.000 months of temperature data with
125 measurement intervals between 1 and 240 minutes (>30% every 60 minutes). The database hosts loggers
126 from 51 different countries spread across all continents, with a broad distribution across the world's
127 climatic space (Fig. 2b). There is a dominance of time series from Europe and areas below 1500 m a.s.l.
128 (Fig. 2c, d). More than 75% of sensor measurements occurred within the last decade, but the database
129 does contain several time series covering longer time periods as well, with a maximum of 42 years (Fig.
130 2d).

131 When the remaining critical gaps in our spatial coverage will be filled (see below), this database will allow
132 global assessments of the long-established theories on boundary layer climatology in heterogeneous
133 environments (Geiger, 1950), which has so far been lacking. The growing database provides a unique
134 opportunity to disentangle the role of the different horizontal and vertical features influencing soil and
135 near-surface temperature across all biomes of the world, with high spatial and temporal resolutions. It
136 will allow relating patterns in soil temperature to processes in the lower air layers and calibrate and
137 validate global models of soil temperature and (micro)climate (Kearney *et al.*, 2014a, Kearney *et al.*,
138 2014b, Carter *et al.*, 2015, Maclean *et al.*, 2017). It will also allow us to create global maps of a wide array
139 of general and microclimate-specific bioclimatic variables (e.g. growing degree days, growing season
140 length) at relevant spatiotemporal resolutions (Körner & Hiltbrunner, 2018).

141 Ultimately, this joint global effort and the resulting global microclimatic products will enable us to
142 improve analyses of the relationships between species' macroecology and the microclimate they
143 experience, identify microrefugia and stepping stones and improve global models of ecosystem
144 functioning and element cycling. Indeed, replacing the coarse-scaled free-air temperature averages used

traditionally in models in all fields of ecology with these more relevant soil-specific data products is likely to increase their descriptive and predictive power, as the countless above-mentioned regional studies exemplify (Lembrechts *et al.*, 2019). Additionally, this first global effort to combine and collect in-situ measurements will help solve long-standing issues regarding sensor comparability and data collection variability (Bramer *et al.*, 2018), as well as address the question at what spatial scale microclimate data can prove most informative for ecological modelling (Jucker *et al.*, 2020). The temperature time series in the database, many of which are covering increasingly long time periods of up to a decade or more, will also allow fine-tuning forecasts of microclimate data into the future by deepening our understanding of the link between microclimatic dynamics in the soil and the air (Lenoir *et al.*, 2017, Wason *et al.*, 2017, Bramer *et al.*, 2018, Maclean, 2019), improving our predictions of biodiversity and ecosystem functioning under climate change.

Dig out your loggers! A call for contributions

To reach these goals, we encourage scientists owning in-situ measured temperature data to submit these to the growing SoilTemp database. All time series spanning one month or more, with temperature measurements a maximum of 4 hours apart, all soil depths, all heights above the ground up till two meters, all biomes, and all sensor types and brands will be accepted. Note that both spatially dense and sparse logger networks, as well as single loggers are accepted. The achieved spatial resolution is dependent on the provision of spatially precise coordinates to achieve a good relationship with potential explanatory variables (e.g. high resolution remotely sensed environmental data). If we have these coordinates and thus the location and distance between loggers, we can effectively obtain the extent and spacing for each logger network (Western *et al.*, 2002).

We include data from both observational and experimental plots, yet sensors have to be measuring in-situ and not in pots, and experiments manipulating the local climate (e.g. open-top chambers, rain-out shelters or vegetation-removal experiments) are excluded (Table 1). Given currently less well-represented climate regions, we especially encourage submissions from extreme cold and hot environments to fill the remaining gaps in our global coverage. More specifically, hot tropical climates (both tropical rainforests and tropical seasonal forests and savannas) and cold and hot deserts are currently still largely underrepresented (Fig. 2b), in particular from Africa, Asia, Antarctica and the Americas (Fig. 2a). Data contributors will be invited as co-authors on the main global papers resulting from this database (see Supplementary Materials for details on terms of use and data ownership).

175 By encouraging sampling and submissions from remote areas, we aim to help solve the global sampling
176 bias in soil ecological data (Cameron *et al.*, 2018, Guerra *et al.*, 2019), and we hope to build a truly global
177 network representing – and actively engaging - scientists from a wide diversity of cultural backgrounds
178 (Maestre & Eisenhauer, 2019). More information is available on the SoilTemp website, accessible via
179 Figshare (DOI 10.6084/m9.figshare.12126516).

180 When fully established, the SoilTemp database and its derivative products (e.g. bioclimatic variables) will
181 be made freely available to facilitate the analysis of global patterns in microclimates, increase the
182 comparability between regional studies and simplify the use of accurate microclimatic data in ecology
183 (Bramer *et al.*, 2018). At the moment, critical metadata is already freely accessible via Figshare (DOI
184 10.6084/m9.figshare.12126516). Given the absence of and the need for globally available soil
185 microclimate data products at relevant spatial resolutions for use in ecological analyses, we believe that
186 SoilTemp has the potential to become a highly important resource that will enable a step change in
187 ecological modelling.

188

189 **Table**

190 *Table 1: Minimal data requirements and obligatory metadata for submission to the database. For more*
191 *details, see Supplementary Material.*

192

Minimum data requirements	Obligatory metadata
Minimum one consecutive month of in-situ measured temperature time series	Accurate (handheld GPS or finer) spatial coordinates of the loggers (+ estimated accuracy)
Maximum time interval between measurements: 4 hours	Height/depth of the sensor relative to the soil surface
No climate manipulation experiments (only control plots of those experiments, or observational studies)	Type or brand of temperature sensor used, and type of shelter (e.g. no shelter, home-made shelter, Stevenson screen...)
No modelling studies (only empirical data)	Temporal resolution of the sensor
	Habitat classification

193

194

196 **Figure 1: The horizontal and vertical drivers of the offset between in-situ soil and free-air temperatures.**

197 Conceptually, there are two different sets of features responsible for the offset between coarse-scale free
198 air temperatures (top left, e.g. WorldClim, Fick & Hijmans, 2017) and fine-scale soil temperatures (bottom
199 right, e.g. Ashcroft & Gollan, 2012, Lembrechts et al., 2019),. Firstly, one can incorporate fine-scale
200 horizontal climate-forcing factors like topography and terrain-related features, land cover types and
201 distance to water bodies to go from coarse-scaled to finer resolutions (top right, e.g. Aalto et al., 2017,
202 Macek et al., 2019). Secondly, one can consider observation height, and the effects of vegetation
203 characteristics (like structure and cover), snow cover and soil characteristics (like moisture, geological
204 types, texture and bulk density) on the radiation balance to convert from free-air to soil temperatures (e.g.
205 Kearney, 2019). Both horizontal and vertical features can introduce positive or negative differences (offset
206 values) between soil and air temperatures through their effects on processes related to the radiation
207 balance, like wind, convective heat transfer and surface albedo. The complexities of these horizontal and
208 vertical processes can vary with biome, season and time of day. Temperatures are represented here using
209 an unspecified temperature range from cold (blue) to warm (red).

Figure 2: Overview of the status of the SoilTemp-database as of March 2020. Spatial (a), climatic (b), elevational (c) and temporal (d) distribution of sensors in the SoilTemp-database as of March 2020. (a) Background world map in WGS1984, hexagons with a resolution of approximately 70.000 km² using the *dggridR*-package in R. (b) Colors of hexagons indicate the number of sensors at each climatic location, with a 40 × 40 bin resolution. Small dots in the background represent the global variation in climatic space (obtained by sampling 1.000.000 random locations from the CHELSA world maps at a spatial resolution of 2.5 arc minutes. Overlay with dotted lines and numbers (from 1 to 9) depict a delineation of Whittaker biomes (adapted from Whittaker, 1970): (1) tundra and ice, (2) boreal forest, (3) temperate seasonal forest, (4) temperate rainforest, (5) tropical rainforest, (6) tropical seasonal forest/savanna, (7) subtropical desert, (8) temperate grassland/desert, (9) woodland/shrubland. (c) Number of sensors in each elevation class. (d) Time span covered by each sensor in the database, ranked by starting date. Data showed from 1992 onwards, note that the time period covered by 4 loggers with starting dates in 1976 is truncated.

Acknowledgments

We thank Sylvain Pincebourde and an anonymous reviewer for their critical evaluation of our manuscript. This work was supported by the Research Foundation Flanders (FWO) through a postdoctoral fellowship to Jonas J. Lembrechts (12P1819N) and a Research Network Grant (WOG W001919N). We gratefully acknowledge all data contributors, all staff of the author institutions engaged in field measurements and equipment maintenance (namely Erik Herberg, Iris Hamersveld, Ida Westman, Fredrik Brounes, Pernille Eidsen, Eleanor Walker and the teachers participating in the Tepäseförsöket 2015) and the ILTER-network, and thank local peoples for permission to collect data on their lands. Temperature data collection on European GLORIA summits was funded by European Union FP-5 project GLORIA-Europe (EVK2-CT-2000-0006) and the Swiss MAVA Foundation project 'Climate change impacts in protected areas of the Alps and high mountains of Eastern Europe and the Mediterranean region', on the Eastern Swiss GLORIA summits by the Swiss Federal Office for the Environment (FOEn), the Research Commission and staff of the Swiss National Park, and the Foundation Dr. Joachim de Giacomini, on Tenerife in the framework of the Flexible Pool project (W47014118) of Sylvia Haider funded by the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, on Livingston Island, Antarctica by different research projects of the Govern of Spain (PERMAPLANET CTM2009-10165-E; ANTARPERMA CTM2011-15565-E; PERMASNOW CTM2014-52021-R), and the PERMATHERMAL arrangement between the University of Alcalá and the Spanish Polar Committee and on the Western Swiss GLORIA summits by Département de la culture et des sports du Valais, Fondation Mariétan, Société académique de Genève, Swiss Federal Office of Education and Science and Swiss Federal Office for the Environment. Jan Wild, Martin Macek, Martin Kopecký, Lucia Hederová, Matěj Man and Josef Brůna were supported by the Czech Science Foundation (project 17-13998S) and the Czech Academy of Sciences (project RVO 67985939), Meelis Pärtel by an Estonian Research Council grant (PRG609) and by the European Regional Development Fund (Centre of Excellence EcolChange), Lena Muffler, Juergen Kreyling, Robert Weigel, Mario Trouillier, Martin Wilmking and Jonas Schmeddes by DFG GraKo 2010 Response, Juha M. Alatalo by Qatar Petroleum (QUEX-CAS-QP-RD-18/19), the authors from Odesa National I. I. Mechnikov University (Sergiy Medinets and Volodymyr Medinets) by EU FP6 The nitrogen cycle and its influence on the European greenhouse gas balance (NitroEurope), EU FP7 Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems (ÉCLAIRE), Ukrainian national research projects (No. 505, 550, 574) funded by Ministry of Education and Science of Ukraine and GEF-UNEP funded 'Towards INMS' project, see www.inms.international for more details. Florian Zellweger was supported by the Swiss National Science Foundation (grant no. 172198), Peter Barančok, Róbert Kanka, Jozef Kollár and Andrej Palaj by the Slovak Scientific Grant Agency (project VEGA 2/0132/18), Jonas Ardö by a infrastructure grant from faculty of Science, Lund University, Julia Kempinen by the Doctoral Programme in Geosciences at the University of Helsinki, Jan Altman by the Czech Science Foundation (projects 17-07378S

and 20-05840Y), the Czech Academy of Sciences (project RVO 67985939) and Ministry of Education, Youth and Sport of the Czech Republic, program Inter-Excellence, subprogram Inter-Action (project LTAUSA19137), Toke Thomas Høye by the Carlsberg Foundation (grant no. CF16-0896) and the Villum Foundation (grant no. 17523), Jiri Dolezal by the Czech Science Foundation (projects 17-19376S), and Ministry of Education, Youth and Sport of the Czech Republic, program Inter-Excellence, subprogram Inter-Action (project LTAUSA18007), Nico Eisenhauer, Felix Gottschall and Simone Cesarz by the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, funded by the German Research Foundation (FZT 118), Stuart W. Smith by AfricanBioServices project funded by the EU Horizon 2020 grant number 641918, Haydn Thomas by a K Natural Environmental Research Council doctoral training partnership grant NE/L002558/1, Isla H. Myers-Smith by the UK Natural Environmental Research Council ShrubTundra Project NE/M016323/1, Anibal Pauchard, Rafael Garcia and Eduardo Fuentes-Lillo by the projects Fondecyt 1180205, Fondecyt 11170516 and CONICYT PIA APOYO CCTE AFB170008, Rafaella Canessa, Maaikje Y. Bader, Liesbeth van den Brink, and Katja Tielbörger by the DFG Priority Programme 1803 EarthShape (projects 1 (BA 3843/6-1) and 11 (TI 338/14-1&2)), Martin Svátek by a grant from the Ministry of Education, Youth and Sports of the Czech Republic (grant number: INTER-TRANSFER LTT17017), Mihai Pușcaș by ODYSSEE project (ANR-13-ISV7-0004 France, PN-II-ID-JRP-RO-FR-2012 UEFISCDI Romania), Pavel Dan Turtureanu by UEFISCDI in Romania, MEMOIRE grant no. PN-III-P1-1.1-PD2016-0925, Jonathan Lenoir by the Agence Nationale de la Recherche (ANR) within the framework of the IMPRINT project "IMpacts des PRocessus microclimatiques sur la redistributiON de la biodiversité forestière en contexte de réchauffement du macroclimat" (grant number: ANR-19-CE32-0005-01), Radim Matula and Roman Plichta by a grant Inter-Excellence (project: INTER-TRANSFER LTT17033) from the Ministry of Education, Youth and Sports of the Czech Republic, Lisa Rew by the National Institute of Food and Agriculture, U.S. Department of Agriculture Hatch MONB00363, Tim Seipel and Christian Larson by a grant from the United States National Institute of Food and Agriculture grant 2017-70006-27272, Nina Buchmann by the SNF (projects M4P 40FA40_154245, ICOS-CH 20FI21_148992, 20FI20_173691, InnoFarm 407340_172433) and the EU (SUPER-G contract no. 774124) for the Swiss FluxNet, Mana Gharun by the SNF project ICOS-CH Phase 2 20FI20_173691, Sanne Govaert by the Research Foundation Flanders (FWO) (project GOH1517N Pieter De Frenne, Camille Meeussen. and Pieter Van Gansbeke by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (ERC Starting Grant FORMICA 757833), Olivier Roupsard by EU-LEAP-Agri (RAMSES II), Agropolis and Total Foundation (DSCATT), CGIAR (GLDC) and EU-DESIRA (CASSECS), Zuzana Sitková by the Slovak Research and Development Agency under the project No. APVV-16-0325 and project ITMS 26220220066 co-funded by the ERDF, Brett Ryan Scheffers by National Geographic Society (grant no. 9480-14 and WW-240R-17), James D. M. Speed by the Research Council of Norway (262064), William D. Pearse and the Pearse Lab by National Science Foundation ABI-1759965, NSF EF-1802605 and United States Department of Agriculture Forest Service agreement 18-CS-11046000-041, Isla H. Myers-Smith by the UK Natural Environmental Research Council ShrubTundra Project NE/M016323/1, Andrew D Thomas by a Leverhulme Trust Research Fellowship under Government of Botswana permit EWT8/ 36/4 VIII(4), Shengwei Zong by National Natural Science Foundation of China (No. 41971124), Roman Plichta by the post-doc project 7.3 of Institutional plan of Mendel University in Brno 2019–2020, František Máliš by the Slovak Research and Development Agency project APVV-15-0270, Filip Hrbacek and Kamil Laska by the projects LM2015078 and CZ.02.01/0.0/0.0/16_013/0001708 of Ministry of Youth and Sports of the Czech Republic, T-M. Ursu was supported by the Ministry of Research and Innovation through Projects for Excellence Financing in RDI: Contract no. 22 PFE/2018 and PN2019-2022/19270201 – Ctr. 25N BIODIVERS 3-BIOSERV and Andrej Varlagin by RFBR project number 19-04-01234-a. Lore T. Verryck is funded by a PhD fellowship from the Research Foundation Flanders (FWO) and acknowledges support from the European Research Council Synergy Grant; ERC-2562013-SyG-610028 IMBALANCE-P and Pallieter De Smedt holds a postdoctoral fellowship of the Research Foundation-Flanders (FWO) and The Kreinitz Experiment is a cooperative research project initiated by the Helmholtz Centre for Environmental Research - UFZ. We also acknowledge project 18-74-10048 from the Russian Science Foundation, the Dirección General de Cambio Climático del Gobierno de Aragón, the Ordesa y Monte Perdido National Park and the Servicio de Medio Ambiente de Soria de la Junta de Castilla y León, the National Swiss Fund for research (SNSF, project "Lif3web", n°162604).

Conflict of Interest: The authors declare that they have no conflict of interest.

294 **References**

- 295 Aalto J, Riihimäki H, Meineri E, Hylander K, Luoto M (2017) Revealing topoclimatic heterogeneity using
296 meteorological station data. *International Journal of Climatology*, **37**, 544-556.
- 297 Aalto J, Scherrer D, Lenoir J, Guisan A, Luoto M (2018) Biogeophysical controls on soil-atmosphere thermal
298 differences: implications on warming Arctic ecosystems. *Environmental Research Letters*, **13**,
299 074003.
- 300 Abatzoglou JT, Dobrowski SZ, Parks SA, Hegewisch KC (2018) TerraClimate, a high-resolution global
301 dataset of monthly climate and climatic water balance from 1958–2015. *Scientific data*, **5**,
302 170191.
- 303 Ashcroft MB, Cavanagh M, Eldridge MDB, Gollan JR (2014) Testing the ability of topoclimatic grids of
304 extreme temperatures to explain the distribution of the endangered brush-tailed rock-wallaby
305 (*Petrogale penicillata*). *Journal of biogeography*, **41**, 1402-1413.
- 306 Ashcroft MB, Chisholm LA, French KO (2008) The effect of exposure on landscape scale soil surface
307 temperatures and species distribution models. *Landscape Ecology*, **23**, 211-225.
- 308 Ashcroft MB, Chisholm LA, French KO (2009) Climate change at the landscape scale: predicting fine-
309 grained spatial heterogeneity in warming and potential refugia for vegetation. *Global change*
310 *biology*, **15**, 656-667.
- 311 Ashcroft MB, Gollan JR (2012) Fine-resolution (25 m) topoclimatic grids of near-surface (5 cm) extreme
312 temperatures and humidities across various habitats in a large (200 x 300 km) and diverse region.
313 *International Journal of Climatology*, **32**, 2134-2148.
- 314 Ashcroft MB, Gollan JR (2013) Moisture, thermal inertia, and the spatial distributions of near-surface soil
315 and air temperatures: Understanding factors that promote microrefugia. *Agricultural and Forest*
316 *Meteorology*, **176**, 77-89.
- 317 Bennie J, Huntley B, Wiltshire A, Hill MO, Baxter R (2008) Slope, aspect and climate: Spatially explicit and
318 implicit models of topographic microclimate in chalk grassland. *Ecological Modelling*, **216**, 47-59.
- 319 Bennie J, Wilson RJ, Maclean IMD, Suggitt AJ (2014) Seeing the woods for the trees - when is microclimate
320 important in species distribution models? *Global change biology*, **20**, 2699-2700.
- 321 Bramer I, Anderson B, Bennie J, Bladon A, De Frenne P, Hemming D, Hill RA, Kearney MR, Körner C,
322 Korstjens AH, Lenoir J, Maclean IMD, Marsh CD, Morecroft MD, Ohlemüller R, Slater HD, Suggitt
323 AJ, Zellweger F, Gillingham PK (2018) Advances in monitoring and modelling climate at
324 ecologically relevant scales. *Advances in Ecological Research*, **58**, 101-161.

325 Bruelheide H, Dengler J, Purschke O, Lenoir J, Jiménez-Alfaro B, Hennekens SM, Botta-Dukát Z, Chytrý M,
 326 Field R, Jansen F (2018) Global trait–environment relationships of plant communities. *Nature*
 327 *ecology & evolution*, **2**, 1906.

328 Cameron EK, Martins IS, Lavelle P, Mathieu J, Tedersoo L, Gottschall F, Guerra CA, Hines J, Patoine G,
 329 Siebert J (2018) Global gaps in soil biodiversity data. *Nature ecology & evolution*, **2**, 1042.

330 Carter A, Kearney M, Mitchell N, Hartley S, Porter W, Nelson N (2015) Modelling the soil microclimate:
 331 does the spatial or temporal resolution of input parameters matter? *Frontiers of Biogeography*, **7**,
 332 138-154.

333 Copernicus Climate Change Service (C3s) (2019) C3S ERA5-Land reanalysis. (ed Copernicus Climate
 334 Change Service).

335 Coûteaux M-M, Bottner P, Berg B (1995) Litter decomposition, climate and litter quality. *Trends in ecology*
 336 *& evolution*, **10**, 63-66.

337 Daly C (2006) Guidelines for assessing the suitability of spatial climate data sets. *International journal of*
 338 *climatology*, **26**, 707-721.

339 De Boeck HJ, Van De Velde H, De Groote T, Nijs I (2016) Ideas and perspectives: Heat stress: more than
 340 hot air. *Biogeosciences*, **13**, 5821-5825.

341 De Frenne P, Rodríguez-Sánchez F, Coomes DA, Baeten L, Verstraeten G, Vellend M, Bernhardt-
 342 Römermann M, Brown CD, Brunet J, Cornelis J (2013) Microclimate moderates plant responses to
 343 macroclimate warming. *Proceedings of the National Academy of Sciences*, **110**, 18561-18565.

344 Fick SE, Hijmans RJ (2017) WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas.
 345 *International Journal of Climatology*, **37**, 4302-4315.

346 Geiger R (1950) *The climate near the ground*, Cambridge, Massachusetts, USA, Harvard University Press.

347 Gottschall F, Davids S, Newiger-Dous TE, Auge H, Cesarz S, Eisenhauer N (2019) Tree species identity
 348 determines wood decomposition via microclimatic effects. *Ecology and evolution*, **9**, 12113-
 349 12127.

350 Goulden M, Wofsy S, Harden J, Trumbore SE, Crill P, Gower S, Fries T, Daube B, Fan S-M, Sutton D (1998)
 351 Sensitivity of boreal forest carbon balance to soil thaw. *Science*, **279**, 214-217.

352 Guerra CA, Heintz-Buschart A, Sikorski J, Chatzinotas A, Guerrero-Ramírez N, Cesarz S, Beaumelle L, Rillig
 353 MC, Maestre FT, Delgado-Baquerizo M (2019) Blind spots in global soil biodiversity and ecosystem
 354 function research. *bioRxiv*, 774356.

355 Hursh A, Ballantyne A, Cooper L, Maneta M, Kimball J, Watts J (2017) The sensitivity of soil respiration to
 356 soil temperature, moisture, and carbon supply at the global scale. *Global change biology*, **23**,
 357 2090-2103.

358 Jarraud M (2008) Guide to meteorological instruments and methods of observation (WMO-No. 8). World
 359 Meteorological Organisation: Geneva, Switzerland.

360 Jucker T, Jackson T, Zellweger F, Swinfield T, Gregory N, Williamson J, Slade E, Phillips J, Bittencourt P,
 361 Blonder B, Boyle M, Ellwood M, Hemprich-Bennett D, Lewis O, Matula R, Senior RA, Shenkin A,
 362 Svatek M, Coomes D (2020) A research agenda for microclimate ecology in human-modified
 363 tropical forests. *Frontiers in Forests and Global Change*, **2**.

364 Karger DN, Conrad O, Böhrer J, Kawohl T, Kreft H, Soria-Auza RW, Zimmermann NE, Linder HP, Kessler M
 365 (2017) Climatologies at high resolution for the earth's land surface areas. *Scientific data*, **4**,
 366 170122.

367 Kattge J, Bönsch G, Diaz S, Lavorel S, Prentice IC, Leadley P, Tautenhahn S, Werner G, Günther A (2019)
 368 TRY plant trait database-enhanced coverage and open access. *Global change biology*, **26**, 119-188.

369 Kearney M, Shine R, Porter WP (2009) The potential for behavioral thermoregulation to buffer “cold-
 370 blooded” animals against climate warming. *Proceedings of the National Academy of Sciences*,
 371 **106**, 3835-3840.

372 Kearney MR (2019) MicroclimOz—A microclimate data set for Australia, with example applications. *Austral*
 373 *Ecology*, **44**, 534-544.

374 Kearney MR, Isaac AP, Porter WP (2014a) microclim: Global estimates of hourly microclimate based on
 375 long-term monthly climate averages. *Scientific data*, **1**, 140006.

376 Kearney MR, Shamakhy A, Tingley R, Karoly DJ, Hoffmann AA, Briggs PR, Porter WP (2014b) Microclimate
 377 modelling at macro scales: a test of a general microclimate model integrated with gridded
 378 continental-scale soil and weather data. *Methods in Ecology and Evolution*, **5**, 273-286.

379 Kissling WD, Walls R, Bowser A, Jones MO, Kattge J, Agosti D, Amengual J, Basset A, Van Bodegom PM,
 380 Cornelissen JH (2018) Towards global data products of Essential Biodiversity Variables on species
 381 traits. *Nature ecology & evolution*, **2**, 1531-1540.

382 Körner C, Hiltbrunner E (2018) The 90 ways to describe plant temperature. *Perspectives in plant ecology*,
 383 *evolution and systematics*, **30**, 16-21.

384 Körner C, Paulsen J (2004) A world-wide study of high altitude treeline temperatures. *Journal of*
 385 *biogeography*, **31**, 713-732.

386 Lembrechts J, Nijs I, Lenoir J (2018) Incorporating microclimate into species distribution models.
 387 *Ecography*, **42**, 1267-1279.

388 Lembrechts JJ, Lenoir J, Roth N, Hattab T, Milbau A, Haider S, Pellissier L, Pauchard A, Ratier Backes A,
 389 Dimarco RD (2019) Comparing temperature data sources for use in species distribution models:
 390 From in-situ logging to remote sensing. *Global Ecology and Biogeography*, **28**, 1578-1596.

391 Lenoir J, Hattab T, Pierre G (2017) Climatic microrefugia under anthropogenic climate change: implications
 392 for species redistribution. *Ecography*, **40**, 253-266.
 393 Li T-T (1926) *Soil temperature as influenced by forest cover*.
 394 Macek M, Kopecký M, Wild J (2019) Maximum air temperature controlled by landscape topography
 395 affects plant species composition in temperate forests. *Landscape Ecology*, **34**, 2541-2556.
 396 Maclean IM (2019) Predicting future climate at high spatial and temporal resolution. *Global change*
 397 *biology*, **26**, 1003-1011.
 398 Maclean IMD, Hopkins JJ, Bennie J, Lawson CR, Wilson RJ (2015) Microclimates buffer the responses of
 399 plant communities to climate change. *Global Ecology and Biogeography*, **24**, 1340-1350.
 400 Maclean IMD, Suggitt AJ, Wilson RJ, Duffy JP, Bennie JJ (2017) Fine-scale climate change: modelling spatial
 401 variation in biologically meaningful rates of warming. *Global change biology*, **23**, 256-268.
 402 Maestre FT, Eisenhauer N (2019) Recommendations for establishing global collaborative networks in soil
 403 ecology. *Soil organisms*, **91**, 73.
 404 Medinets S, Gasche R, Kiese R, Rennenberg H, Butterbach-Bahl K (2019) Seasonal dynamics and profiles of
 405 soil NO concentrations in a temperate forest. *Plant and Soil*, **445**, 335-348.
 406 Meineri E, Hylander K (2017) Fine-grain, large-domain climate models based on climate station and
 407 comprehensive topographic information improve microrefugia detection. *Ecography*, **40**, 1003-
 408 1013.
 409 Niittynen P, Luoto M (2017) The importance of snow in species distribution models of arctic vegetation.
 410 *Ecography*, **41**, 1024-1037.
 411 Opedal OH, Armbruster WS, Graae BJ (2015) Linking small-scale topography with microclimate, plant
 412 species diversity and intra-specific trait variation in an alpine landscape. *Plant Ecology & Diversity*,
 413 **8**, 305-315.
 414 Pincebourde S, Casas J (2019) Narrow safety margin in the phyllosphere during thermal extremes.
 415 *Proceedings of the National Academy of Sciences*, **116**, 5588-5596.
 416 Pincebourde S, Murdock CC, Vickers M, Sears MW (2016) Fine-scale microclimatic variation can shape the
 417 responses of organisms to global change in both natural and urban environments. *Integrative and*
 418 *Comparative Biology*, **56**, 45-61.
 419 Pleim JE, Gilliam R (2009) An indirect data assimilation scheme for deep soil temperature in the Pleim–Xiu
 420 land surface model. *Journal of Applied Meteorology and Climatology*, **48**, 1362-1376.
 421 Portillo-Estrada M, Pihlatie M, Korhonen JFJ, Levula J, Frumau AKF, Ibrom A, Lembrechts JJ, Morillas L,
 422 Horvath L, Jones SK, Niinemets U (2016) Climatic controls on leaf litter decomposition across

423 European forests and grasslands revealed by reciprocal litter transplantation experiments.
 424 Biogeosciences, **13**, 1621-1633.

425 Pradervand J-N, Dubuis A, Pellissier L, Guisan A, Randin C (2014) Very high resolution environmental
 426 predictors in species distribution models: Moving beyond topography? Progress in Physical
 427 Geography, **38**, 79-96.

428 Randin CF, Vuissoz G, Liston GE, Vittoz P, Guisan A (2009) Introduction of snow and geomorphic
 429 disturbance variables into predictive models of alpine plant distribution in the Western Swiss Alps.
 430 Arctic, Antarctic, and Alpine Research, **41**, 347-361.

431 Rosenberg NJ, Kimball B, Martin P, Cooper C (1990) From climate and CO₂ enrichment to
 432 evapotranspiration. Climate change and US water resources., 151-175.

433 Schimel DS, Braswell B, Mckeown R, Ojima DS, Parton W, Pulliam W (1996) Climate and nitrogen controls
 434 on the geography and timescales of terrestrial biogeochemical cycling. Global Biogeochemical
 435 Cycles, **10**, 677-692.

436 Slavich E, Warton DI, Ashcroft MB, Gollan JR, Ramp D (2014) Topoclimate versus macroclimate: how does
 437 climate mapping methodology affect species distribution models and climate change projections?
 438 Diversity and Distributions, **20**, 952-963.

439 Suggitt AJ, Gillingham PK, Hill JK, Huntley B, Kunin WE, Roy DB, Thomas CD (2011) Habitat microclimates
 440 drive fine-scale variation in extreme temperatures. Oikos, **120**, 1-8.

441 Suggitt AJ, Wilson RJ, Isaac NJ, Beale CM, Auffret AG, August T, Bennie JJ, Crick HQ, Duffield S, Fox R
 442 (2018) Extinction risk from climate change is reduced by microclimatic buffering. Nature Climate
 443 Change, **8**, 713.

444 Vitasse Y, Klein G, Kirchner JW, Rebetez M (2017) Intensity, frequency and spatial configuration of winter
 445 temperature inversions in the closed La Brevine valley, Switzerland. Theoretical and applied
 446 climatology, **130**, 1073-1083.

447 Wason JW, Bevilacqua E, Dovciak M (2017) Climates on the move: Implications of climate warming for
 448 species distributions in mountains of the northeastern United States. Agricultural and Forest
 449 Meteorology, **246**, 272-280.

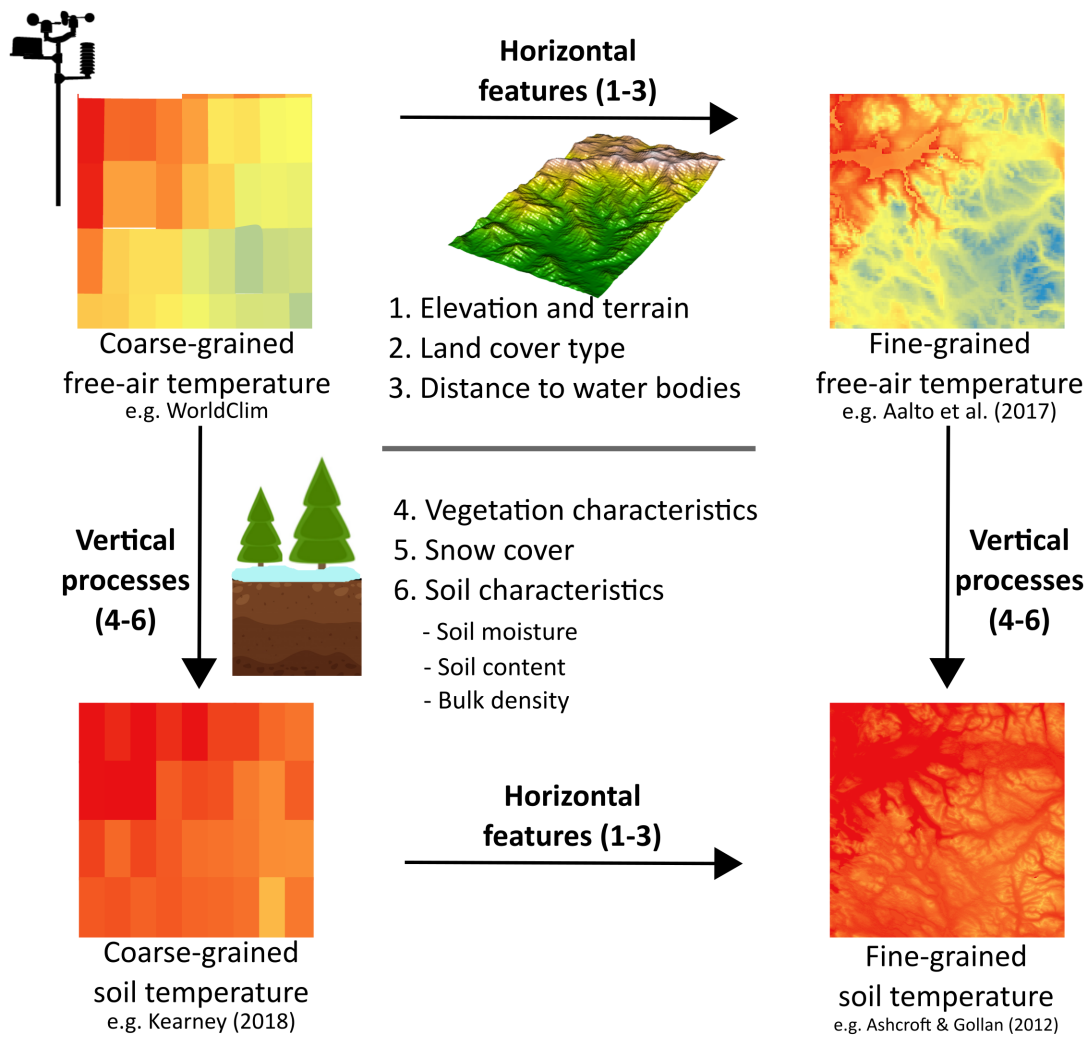
450 Western AW, Grayson RB, Blöschl G (2002) Scaling of soil moisture: A hydrologic perspective. Annual
 451 review of earth and planetary sciences, **30**, 149-180.

452 Whiteman CD (1982) Breakup of temperature inversions in deep mountain valleys: Part I. Observations.
 453 Journal of Applied Meteorology, **21**, 270-289.

454 Whittaker RH (1970) Communities and ecosystems. Communities and ecosystems.

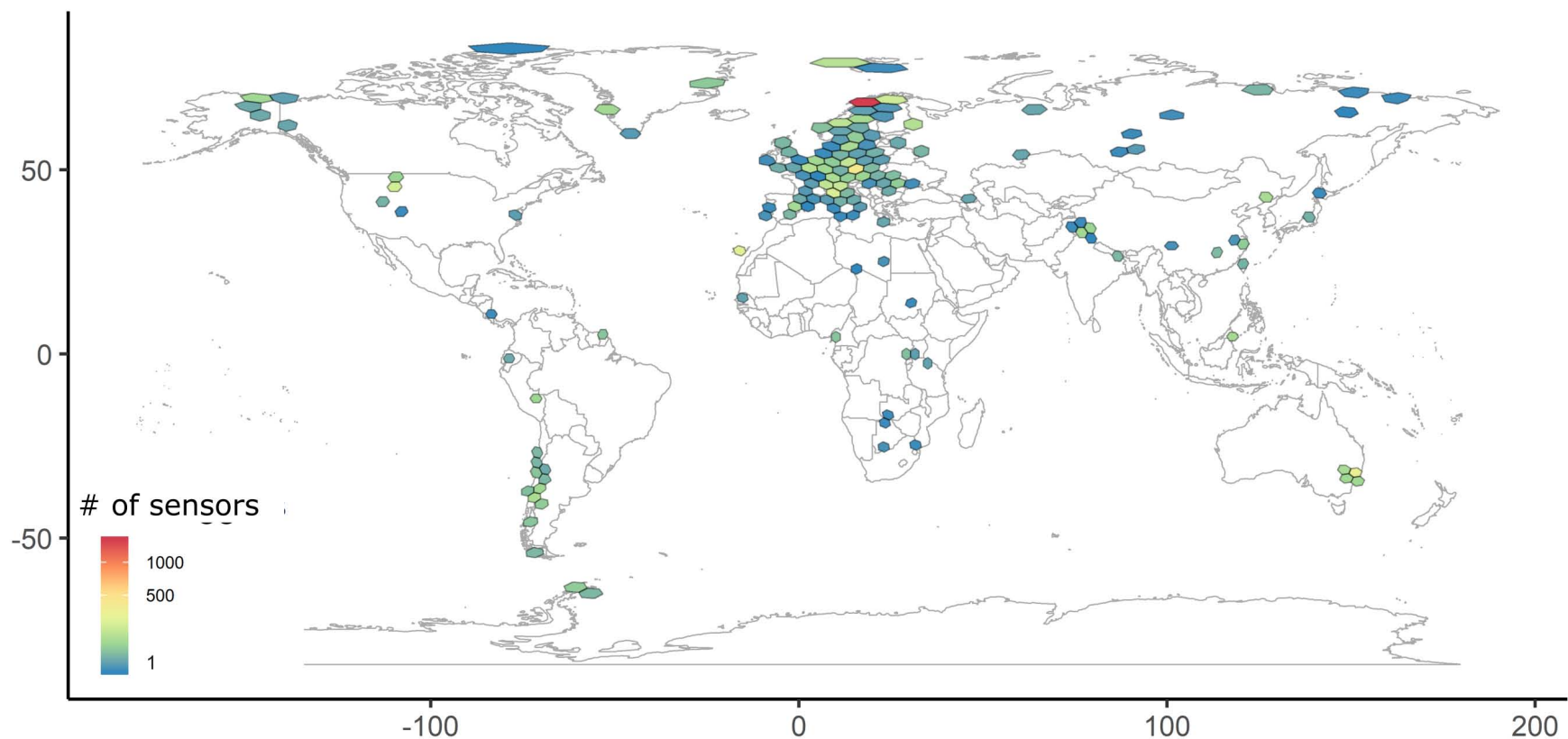
455 Zellweger F, De Frenne P, Lenoir J, Rocchini D, Coomes D (2019) Advances in microclimate ecology arising
456 from remote sensing. *Trends in ecology & evolution*, **34**, 327-341.
457 Zhang Y, Wang S, Barr AG, Black T (2008) Impact of snow cover on soil temperature and its simulation in a
458 boreal aspen forest. *Cold Regions Science and Technology*, **52**, 355-370.

459

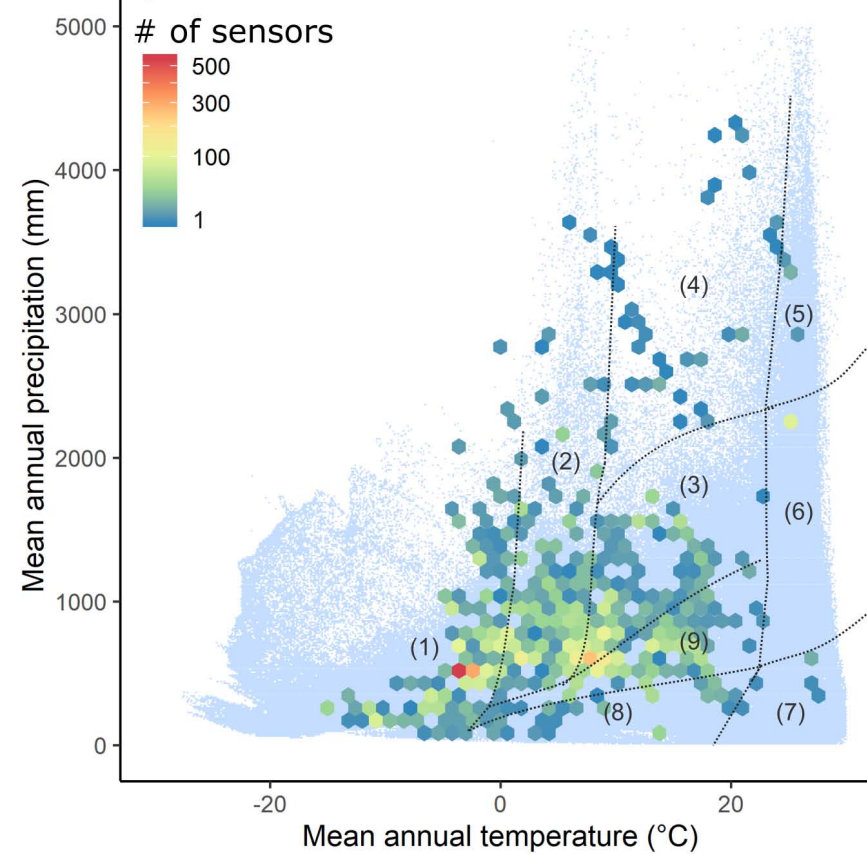


gcb_15123_f1.png

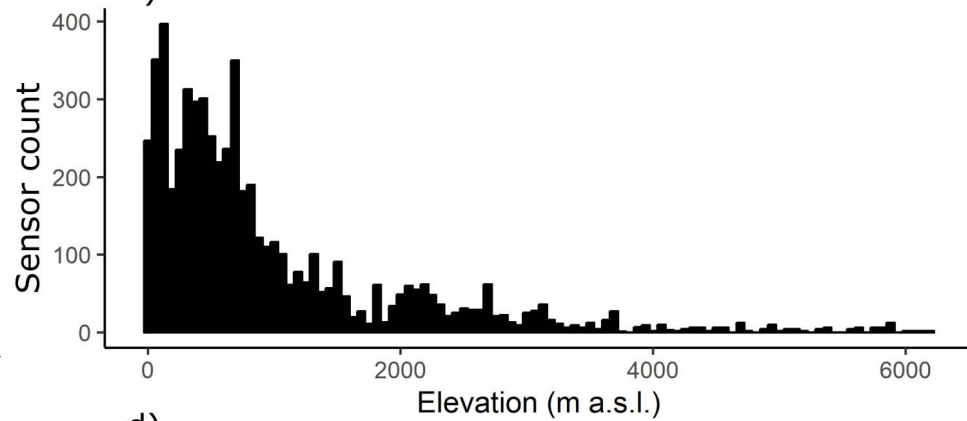
a)



b)



c)



d)

